Ultra-Lightweight Borosilicate Gas-Fusion™ Demonstrator Mirror

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NASA Marshall Space Flight Center

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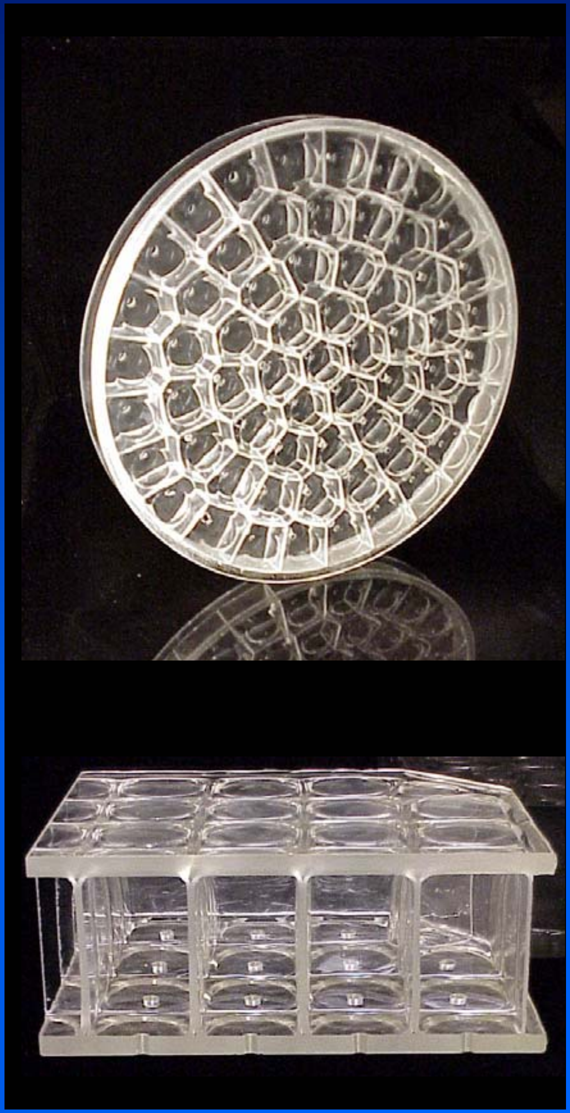
Company Background

- Founded in 1985
  - Technology Spin-Off from U of AZ Steward Observatory Mirror Lab
    - Created as a means to mass produce lightweight, robust, low cost mirrors for large space borne arrays.
  - First project to supply 110+ mirrors for Los Alamos
    - Aurora Laser Fusion Project
- Specialize in ...

  Large lightweight mirrors & substrates
  - Gas-Fusion™ and casting technologies
  - Sizes up to 2500 mm diameter
  - Meter class "Work Horse" size
  - Areal Densities from 100 to <15 kg/m^2
  - Lightweighting from 60 to >90%

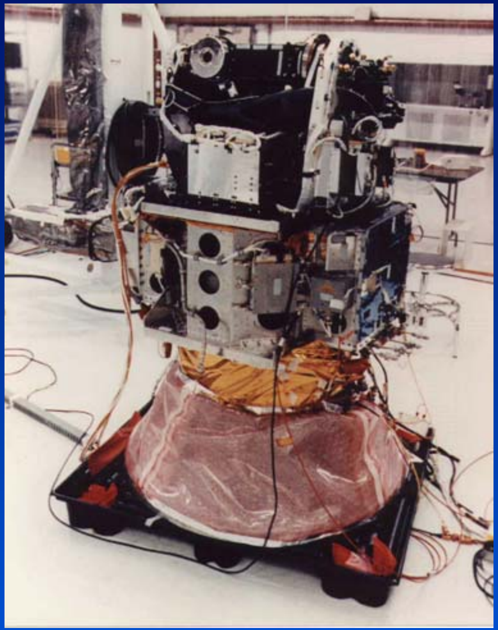
Gas-Fusion™ Substrate Features

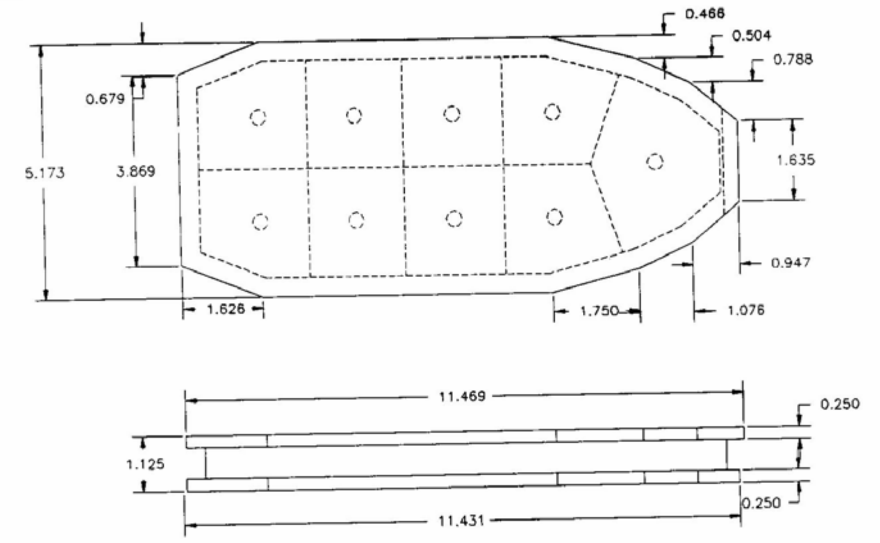
- Closed-back honeycomb structure - high stiffness
- Fused at high temperatures & pneumatic pressure to create cell structure
  - 100% Fusion Bonds
- Robust Construction
  - Radius Corners at Cell/Faceplate intersection
- Highly flexible geometry designs
- High Degree of Customization
- Capable of High Optical Finishes
- Proven to 1.5 m diameter - larger possible
- Fast Manufacturing Cycle Times
  - Lead times do not scale with size
- Proven success in space.



Space Heritage

- BMDO - MSTI-3 Satellite
- Visible and IR wavelengths
- Operating Temp: -40°C to -60°C





Gas-Fusion™ Scanning Flat

- ~6 mm face and back plates
- Weight: <2.4 lbs. before polishing.
- Polished face and back
- Final face finish λ/5 @633 nm

Photo courtesy Spectrum Astro

Issues facing NASA for space based optical systems

- Cost and schedule constraints represent significant hurdles for NASA to achieve its objectives for space based systems.
  - Primary Mirror is a key driver
    - Weight
    - Cost
    - Schedule
    - Risk
- Opportunity
  - How to reduce cost, schedule and risk?

Why Borosilicate Glass?

- Reliable consistent quality (Schott Borofloat®)
- Readily available
- Low cost material

- Published material CTE performance excellent at cryogenic temperatures
  - Near zero CTE at 30-50 ° K

Cryogentic Material Data

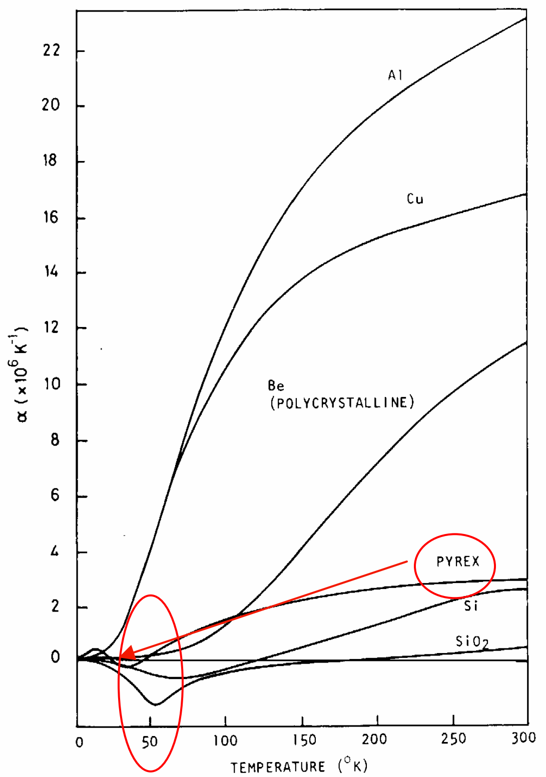


Figure 1. Thermal expansivity of some common materials.

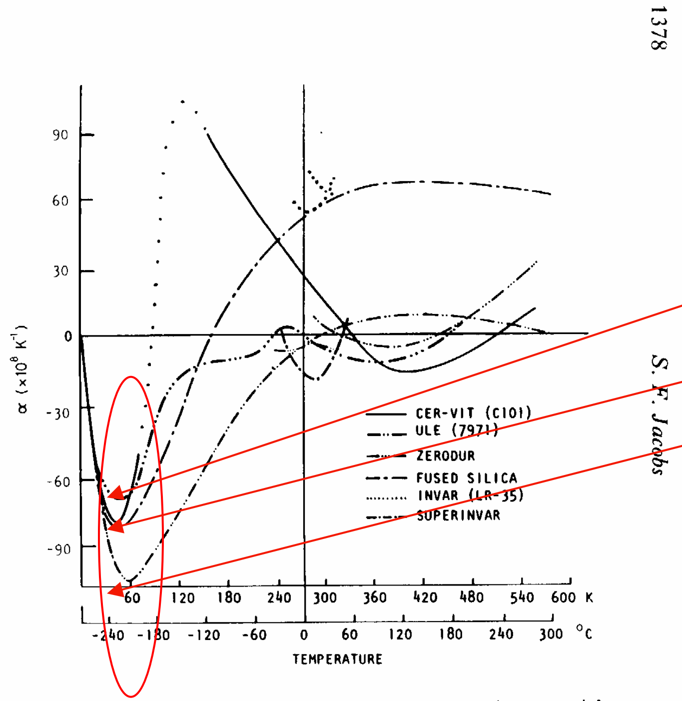


Figure 2. Thermal expansivity of some ultralow-expansion materials.

CTE at 30-50 °K ppm	
Pyrex	~0.1
Zerodur	~0.7
SiO2	~0.8
ULE	~1.0

Chart courtesy: S. F. Jacobs

Project Objectives

- Demonstrate the Gas-Fusion™ substrate technology is capable of 15 kg/m^2 areal density
- Produce a 250 mm borosilicate demonstrator mirror substrate for NASA MSFC to test cryogenically.
  - Provide real time data on Gas-Fusion™ borosilicate mirror technology

General Project Flow

- ***HEXTEK***
  - Acquire & test materials for CTE
  - Low density trials
  - Produce 250 mm demonstrator blank
  - Precision slump to curve
- NASA MSFC
  - Finish mirror to specification
  - Cyro cool and measure changes in the mirror

Planned Cryogenic Testing

- Conduct tests at NASA MSFC X-Ray Cryogenic Facility
  - Utilize 1 m x 2 m chamber
  - Mount mirror on 2 point mount
  - High Speed Phase-Shift Interferometer
  - Watch it at center of curvature
- Characterize substrate performance at various cryogenic temperatures:
  - Surface figure (wave front) change as a function of temperature
  - Radius of Curvature
  - Repeatability - Predictability
  - Measure multiple steps on the way down.
    - Target Temperature: 30 ° K (-5 + 20 ° K)

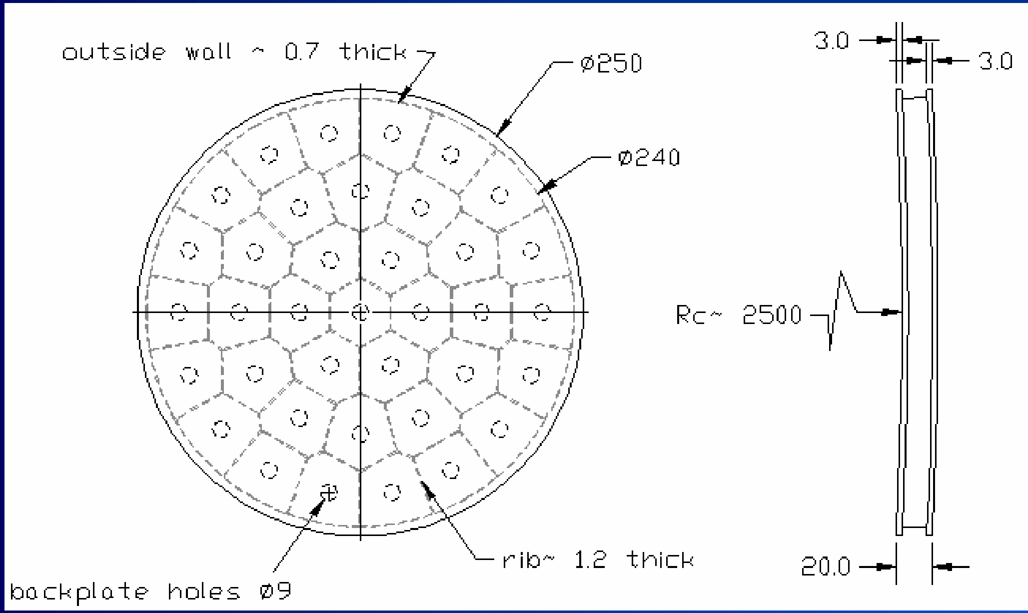
Expected Significance to NASA

- Provide valuable performance data on an alternative substrate technology
- Provide access to a technology that is scalable, robust, space proven, and rapidly produced
- Cost Effective
  - Substrate cost a fraction of competing technologies
  - Total system savings due to shorter lead times on a long lead item.
- Reduce risk
  - Cost
  - Schedule
  - Performance

Manufacturing Design Considerations

- Practical Design
  - Meet areal density target
  - Facilitate conventional ultra-lightweight polishing
- CTE Matching of Face and Back Plates
  - Cut from the same sheet of glass
  - Test plates and core glass for actual CTE to 10 parts per billion

250 mm Demonstrator Design



HEXTEK Design Details

- Diameter: 250 mm
- ROC: 2500 mm (f/5)
- Face & back plate thickness: 3 mm
- Cell wall thickness: 0.5 - 1.2 mm
- Cell Count: 37 mm
- Cell span:~43 mm
- Thickness: 20 mm
- Areal Density
  - before Polishing: 15.3 kg/m^2
  - after Polishing: 14.2 kg /m^2

Blank Fabrication

- Fused Plano first.
- Second, generated edges to diameter, prior to slumping.

Precision Slumping

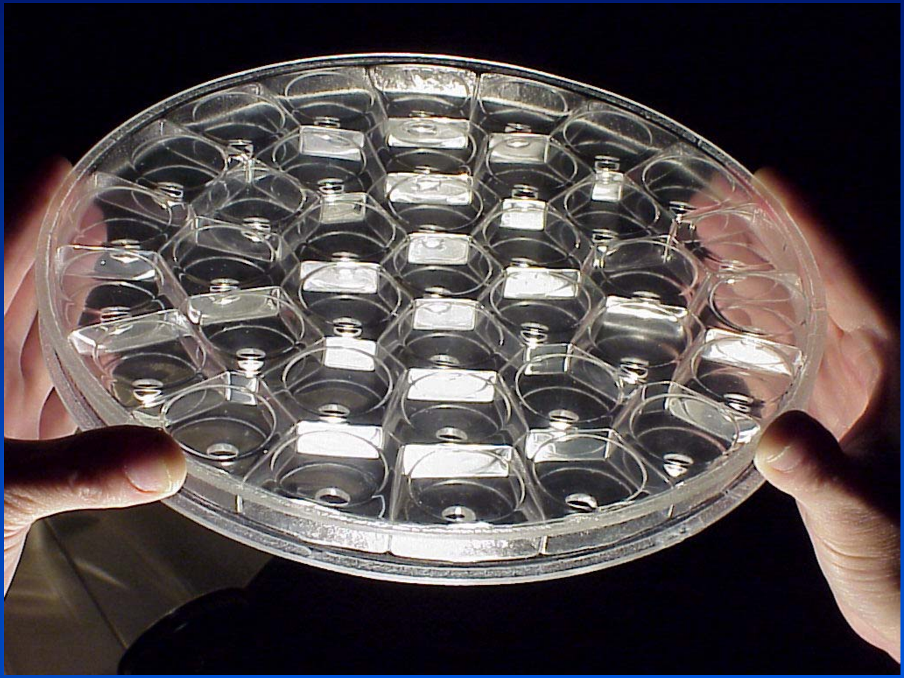
- 300 mm fused silica slump mold generated to curve and polished to facilitate accurate slumping

Precision Slumping

- Pre slumping.
  - Plano blank positioned on the SiO_2 mold
- Post slumping
  - Blank is mated to the mold

Finished Blank

- Slumped surface accurate to within 0.18 mm
- Minimal faceplate material removal
- Achieved areal density target



250 mm HEXTEK Gas-Fusion™ Ultra-Lightweight				
	Thickness as Fused	Thickness as Finished (NASA)	Weight Finished (NASA)	Areal Density (NASA)
Core / Ribs	0.5 – 1.3 mm	0.5 – 1.3 mm	0.105 kg	2.1 kg/m2
Face Plate	3.0 mm	2.5 mm	0.273 kg	5.6 kg/m2
Back Plate	3.0 mm	3.0 mm	0.320 kg	6.5 kg/m2
Total			0.698 kg	**14.2 kg/m2**

Mirror Finishing (NASA MSFC)

- ROC: ~2500 mm spherical
- <15 kg/m² areal density target post polishing
- Finish: 50-63 nm rms
- Surface Roughness: < 4 nm (< 2 nm expected)

Photo courtesy NASA MSFC

Projected Lightweighting Capability

- Current 250 mm demonstrator blank is capable of meeting <8 kg/m^2.
  - Thinning face plates

250 mm HEXTEK Gas-Fusion™ Ultra-Lightweight				
Additional Lightweighting Capability				
	Thickness as Fused	Thickness as Finished	Weight Finished	Areal Density
Core / Ribs	0.5 – 1.3 mm	0.5 – 1.3 mm	0.105 kg	2.1 kg/m2
Face Plate	3.0 mm	1.0 mm	0.109 kg	2.2 kg/m2
Back Plate	3.0 mm	1.5 mm	0.160 kg	3.3 kg/m2
Total			0.368 kg	**7.6 kg/m2**

- Areal Densities for larger 1 m sizes
  - Expect to be able to achieve <13 kg/m^2 with current core design
  - Have not pushed technology to failure

Projected Scalability

- Standard Gas-Fusion™ technology proven to 1.5 m
- Ultra-lightweight design should follow same size capability.

Projected Lead Times

- 1 meter Standard Lightweight Gas-Fusion™
  - 3-4 months first substrate
    - tooling, material acquisition, and back-log
  - <1 month for each additional substrate

- 1 meter Ultra-Lightweight Gas-Fusion™
  - 4-6 months first substrate
    - tooling, material acquisition and cte testing
  - <1 month for each additional substrate

Summary

- Hextek Gas-Fusion™ technology capable of meeting the 15 kg/m^2 area density requirement
  - Current blank can be finished to <8 kg/m^2
- Blank is complete and in polishing at MSFC
- First Cryogenic testing opportunity in the Fall ‘03
- Positive results from cryogenic testing will provide NASA and community with access to a rapidly produced, cost effective, scaleable, high performance source of mirror substrates for cryogenic operating temperatures.

Thank You